New early signals to quantify the magnitude of strong earthquakes

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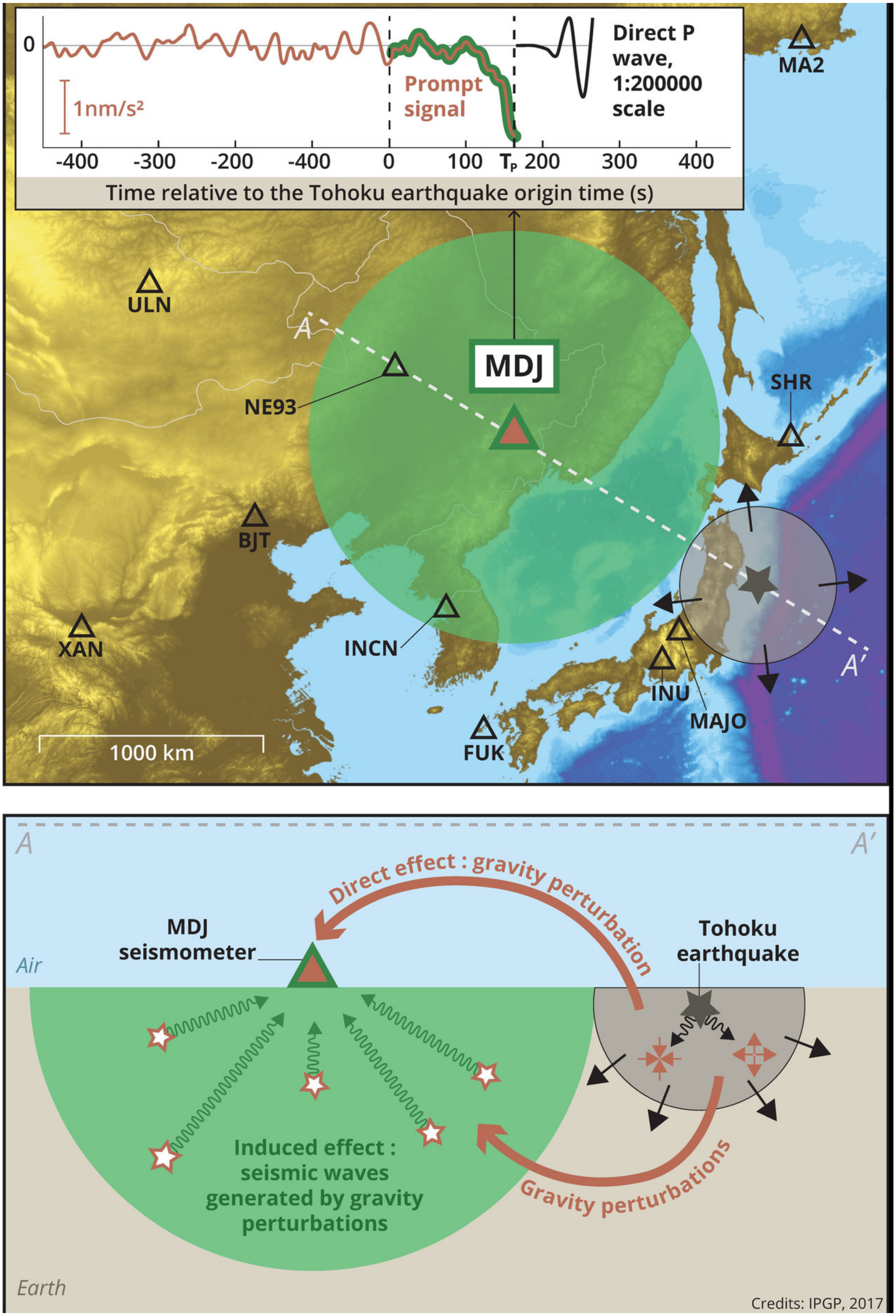
0
1nm/s²
Prompt signal
Direct P wave, 1:200000 scale
-400 -300 -200 -400 0 100 T_P 200 300 400
Time relative to the Tohoku earthquake origin time (s)
MA2
ULN
A
NE93
MDJ
SHR
BJT
XAN
INCN
INU
MAJO
FUK
A'
1000 km
A
A'
Direct effect : gravity perturbation
MDJ seismometer
Tohoku earthquake
Air
Induced effect : seismic waves generated by gravity perturbations
Gravity perturbations
Earth
Credits: IPGP, 2017

Observation and origin of the elastogravity signal preceding direct seismic waves. The map shows the location of the seismometers (triangles) detecting the prompt signals just after the beginning of the Tohoku earthquake (Japan, 11 March 2011, magnitude 9.1), indicated by the black star. We focus here on one of the stations (MDJ), located in north-east China, 1280km away from the Tohoku earthquake. At such distances, direct seismic waves arrive about 165 s after the earthquake starts, as shown in the inset reproducing the MDJ vertical seismogram. However, a clear, even if much weaker, acceleration signal is detected by the seismometer before the direct waves arrival. The origin of such signal can be understood by considering a time after the earthquake onset but before the arrival of the direct seismic waves. For example, about 55 s after origin time, direct waves have propagated inside the volume shown by the grey area, but are still far from arriving at MDJ station. However, inside this volume, seismic waves have caused compressions and dilations of the medium (as further indicated in the bottom cross-section), and the global contribution of all such elements whose mass has changed gives rise to a gravity perturbation, immediately detected by the seismometer (direct effect). The gravitational field is also modified everywhere in the Earth, and each of the elements affected by these perturbations is a secondary source of seismic waves (induced effect). In the green volume around the seismometer, this secondary seismic wavefield arrives before the direct waves. The seismometer therefore records a prompt elastogravity signal, due to the direct and induced effects of the gravity perturbations. Credit: IPGP, 2017

After an earthquake, there is an instantaneous gravitational disturbance that could be recorded before the seismic waves that seismologists can detect. In a study published in *Science* on December 1, 2017, a team comprising researchers from CNRS, IPGP, the Université Paris Diderot and Caltech has managed to observe these weak signals related to gravity and to understand where they come from. Because they are sensitive to the magnitude of earthquakes, these signals may play an important role in the early identification of the occurrence of a major earthquake.

This work came out of the interaction between seismologists who wanted to better understand earthquakes and physicists who were developing fine gravity measurements with a view to detecting gravitational waves. Earthquakes brutally change the equilibrium of forces on Earth and emit seismic waves whose consequences can be devastating. But these same waves also disturb the Earth's field of gravity, which produces a different signal. This is particularly interesting with a view to fast quantification of tremors, because it moves at the speed of light, unlike tremor waves, which propagate at speeds between three and 10 km/s. So seismometers at a station located 1000 km from the epicenter may potentially detect this signal more than two minutes before the seismic waves arrive.

The work presented here follows on a 2016 (J.-P. Montagner et al., *Nat. Commun*. 7, 13349 (2016)) study that demonstrated this signal for the first time. First, the scientists observed these signals on the data from about 10 seismometers located between 500 and 3000 km from the epicenter of the 2011 Japanese earthquake (magnitude 9.1). From their observations, the researchers then demonstrated that these signals were due to two effects. The first is the gravity change that occurs at the location of the seismometer, which changes the equilibrium position of the instrument's mass. The second effect, which is indirect, is due to the gravity change everywhere on Earth, which disturbs the equilibrium of the forces and produces new seismic waves that will reach the seismometer.

Taking account of these two effects, the researchers have shown that this gravity-related signal is very sensitive to the earthquake's magnitude, which makes it a good candidate for rapidly quantifying the magnitude of strong earthquakes. The future challenge is to exploit this signal for magnitudes below about eight to 8.5, because below this threshold, the signal is too weak relative to the seismic noise emitted naturally by Earth, and dissociating it from this noise is complicated. So Researchers plan to test several technologies, including some inspired from instruments developed to detect gravitational waves.

More information: Martin Vallée et al, Observations and modeling of the elastogravity signals preceding direct seismic waves, *Science* (2017). DOI: 10.1126/science.aao0746

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